EETS 8316
Wireless Networks
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Lecture: LTE Scheduling and DRX
http://lyle.smu.edu/~skangude/eets8316.html

Shantanu Kangude
skangude@lyle.smu.edu

SMU ENGINEERING

Scheduling & Rate Control

Scheduler operation

Signalling of scheduler decisions

Measurements to support scheduler operation

UL MAC Scheduling at the UE

- Determines which bearers get how much of the allocation at the UE
  - Essentially within-UE scheduling
- Works on grants received from the eNB
- Simpler than the eNB based scheduling
- MAC tells RLC to send Xi bits from logical channel i
- Scheduler based on Bearer's QoS requirements

MAC Scheduling at the eNB

- Significantly more complex than at UE
- eNB controls channel usage in **both UL & DL**
- Factors affecting scheduling
  - Traffic volume for each bearer at each UE
    - Schedule UEs with bearers having backlog
  - QoS Requirements of each bearer at each UE
    - Priority Schedule, as well as allocate resources in proportion to QoS guarantees
  - Radio conditions at UEs
    - Identified through
      - Measurements made at the eNB, and/or
      - Measurements reported by the UE
    - Schedule radio resources as per good radio conditions for UEs

Radio Resource Allocations

- Described by
  - Resource Block Locations
  - Modulation and Coding Scheme
- Can be valid for
  - 1 Transmit Time Interval (TTI) or Subframe
  - Longer than 1 TTI
    - Require additional information allocation time, allocation repetition factor etc. to specify
    - Also called **Semi-Persistent Scheduling**

Persistent Allocations?

- Typical 1 TTI allocations are for 1 subframe only
  - Suitable for bursty, unpredictable, and download type of traffic
  - Every new allocation needs indication and channel capacity usage on PDCCH
- What if an identical allocation needs to be done periodically?
  - Some bearers, like for VOIP, are periodic
  - And every packet carries identical amount of data
  - Allocation pattern and size is DETERMINISTIC
- What if the allocation overhead in PDCCH per data octet transferred is ALSO high?
  - VOIP example: Packets are small, and happen every 20 ms for a deterministic pattern and size of allocation
- **Efficiency Solution: Allocate once for periodic resources = Persistent Allocation**

Challenges with Persistent Allocations

- Resource Block Channel Conditions Change
  - Allocated frequency carriers may change to have worse channel conditions than other Resource Blocks (RBs)
    - May need to move the RB location
- May need to alter periodicity of a persistent allocation over time
  - E.g. VOIP silence periods need transmissions less often than talk periods
- May need to suspend or pause persistent allocations

Persistent allocations with the above changes allowed = Semi-persistent allocations

Downlink Allocations by the eNB

- Dynamic allocations (Regular allocations)
  - On PDCCH for usage of PDSCH
  - Physical RB and Modulation Coding Scheme
- Semi-persistent allocations
  - Only for the **first HARQ transmission** of packets (of course, ReTxs are unpredictable)
  - RRC defines the periodicity of the semi-persistent downlink grant
  - PDCCH indicates whether the downlink grant is a semi-persistent one i.e. whether it can be implicitly reused in the following TTIs according to the periodicity defined by RRC

When needed, HARQ RETX always explicitly signaled via PDCCH

Downlink Data: PDCCH-Semi-persistent Interactions

- Core concept PDCCH always overrides semi-persistent allocations
  - In the sub-frames where the UE has semipersistent downlink resource, if the UE cannot find its C-RNTI on the PDCCH(s), a downlink transmission according to the semi-persistent allocation that the UE has been assigned in the TTI is assumed
  - In sub-frames where the UE has semi-persistent downlink resource, if the UE finds its C-RNTI on the PDCCH(s), the PDCCH allocation overrides the semi-persistent allocation for that TTI and the UE does not decode the semi-persistent resources

Uplink Allocations by the eNB

- Dynamic Allocations (Regular)
  - Identical to DL dynamic allocations
  - Done in PDCCH with PRB location and MCS
- Semi-persistent Allocations (similar to the DL version)
  - RRC defines periodicity
  - PDCCH indicates if the allocation is semi-persistent or not
  - *One difference from DL: HARQ for UL is Synchronous => even allocations for retransmissions can be IMPLICIT*

Uplink Data: PDCCH, Semi-persistent, and Synchronous HARQ Interactions

- Core concept: PDCCH always overrides
  - In sub-frames where UE has semi-persistent UL resource, if it cannot find its C-RNTI on the PDCCH(s), a UL TX according to the semi-persistent allocation that the UE has been assigned in the TTI can be made. N/W performs decoding of the pre-defined PRBs according to the pre-defined MCS
  - In sub-frames where UE has semi-persistent UL resource, if it finds its C-RNTI on the PDCCH(s), the PDCCH allocation overrides the persistent allocation for that TTI and the UE's TX follows the PDCCH allocation, not the semipersistent
  - ReTxs are either implicitly allocated in which case the UE uses the semi-persistent uplink allocation, or explicitly allocated via PDCCH(s) in which case the UE does not follow the semi-persistent allocation

Measurements to Support Scheduling

- Measurement reports required from the UE to support both UL and DL scheduling by eNB
  - Traffic Volume
    - Uplink buffer status reports (BSR) are needed to provide support for QoS-aware packet scheduling
  - Channel conditions at various carriers
    - CQI reporting for scheduling

Buffer Status Reports & Logical Channel Gorups

- Traffic volume is reported in Buffer Status Reports (BSRs)
- To simplify BSRs, logical channels are grouped into **4 logical channel groups (LCG)**
  - Reporting is aggregate on each LCG
  - Example
    - All web and ftp can be in 1 group
    - All control and high priority VOIP in another group
- 2 formats for BSRs
  - Short format: Only 1 LCG reported (any 1)
  - Long format: All 4 LCGs reported
- BSRs are sent using MAC Signaling (as against RRC signaling)

CQI Reporting

- Channel Quality Indicator (CQI) reports indicate the conditions as seen in the DL by the UE
- CQI reports can be configured to be sent
  - Periodic, **and/or**
  - Aperiodic
- CQI reporting is configured by the eNB, which assigns time/frequency resources for transmission
  - If both Aperiodic and Periodic report scheduled for the same subframe – ONLY Aperiodic one is sent
- 3 types
  - **Wideband, Multiband, and MIMO CQI report types**

Periodic and Aperiodic CQI Reports

- Aperiodic
  - The report is scheduled by the eNB via the PDCCH
  - Transmitted together with uplink data on PUSCH
- Periodic
  - When the UE is allocated PUSCH resources in a subframe where a periodic CQI report is configured to be sent, the periodic CQI report is transmitted together with uplink data on the PUSCH
  - Otherwise, the periodic CQI reports are sent on the PUCCH

Core concept: Try the best to send all reports on PUSCH… if not possible, use PUCCH

Note: Size and Format depends on whether Aperiodic/Periodic and whether on PUCCH/PUSCH

DRX

A good reference at:

http://www.sharetechnote.com/html/MAC_LTE.html#DRX

Following figures are sourced from the above URL

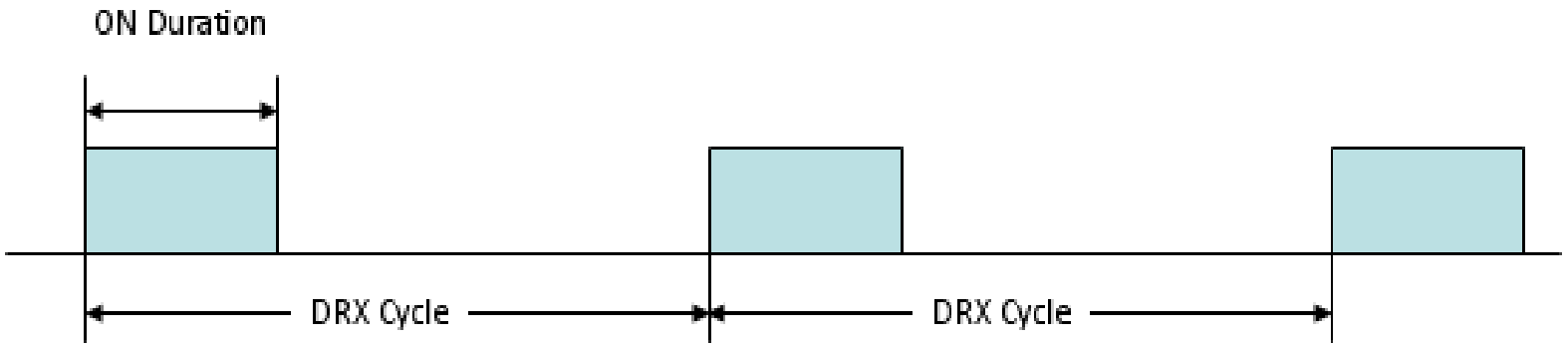
Discontinuous Reception (DRX)

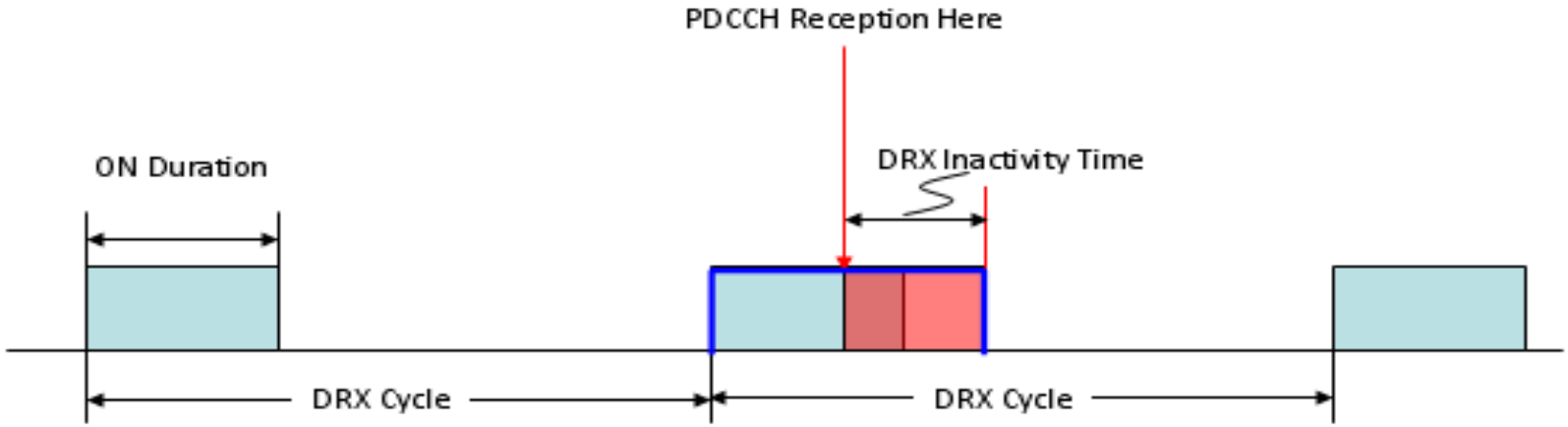
- Normally UE required to read PDCCH for allocations in ALL SUBFRAMES
- DRX is a powersave mechanism with
  - Available-Unavailable RX cycles/periods
- Like Doze/Awake Periods in Wifi Powersave
- Can happen in both RRC states
  - In RRC_IDLE: Longer “unavailable” periods, and paging done when “available”
  - In RRC_CONNECTED: Typically shorter “unavailable” periods, and CRNTI based regular allocations when “available”
- No special RRC or MAC states designated for DRX
- Per UE mechanism (as opposed to per bearer)

DRX Definitions (1/2)

- **On-duration**: Duration in downlink subframes that the UE waits for, after waking up from DRX, to receive PDCCHs. If the UE successfully decodes a PDCCH, the UE stays awake and starts the inactivity timer
- I**nactivity-timer**: Duration in downlink subframes that the UE waits to successfully decode a PDCCH, from the last successful decoding of a PDCCH, failing which it re-enters DRX. The UE shall restart the inactivity timer following a single successful decoding of a PDCCH for a first transmission only (i.e. not for retransmissions)

DRX Basics

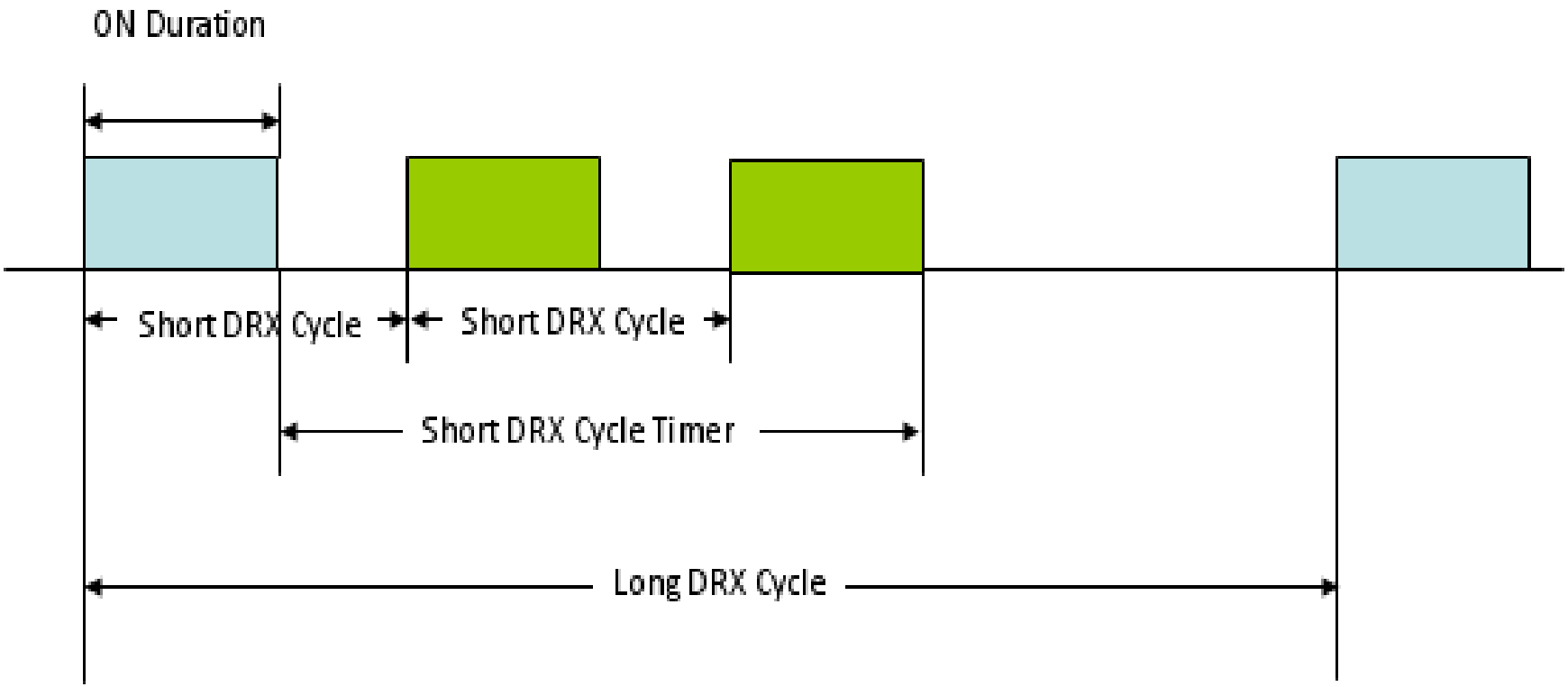

ON Duration
DRX Cycle
DRX Cycle


PDCCH Reception Here
DRX Inactivity Time
ON Duration
DRX Cycle
DRX Cycle

DRX Definitions (2/2)

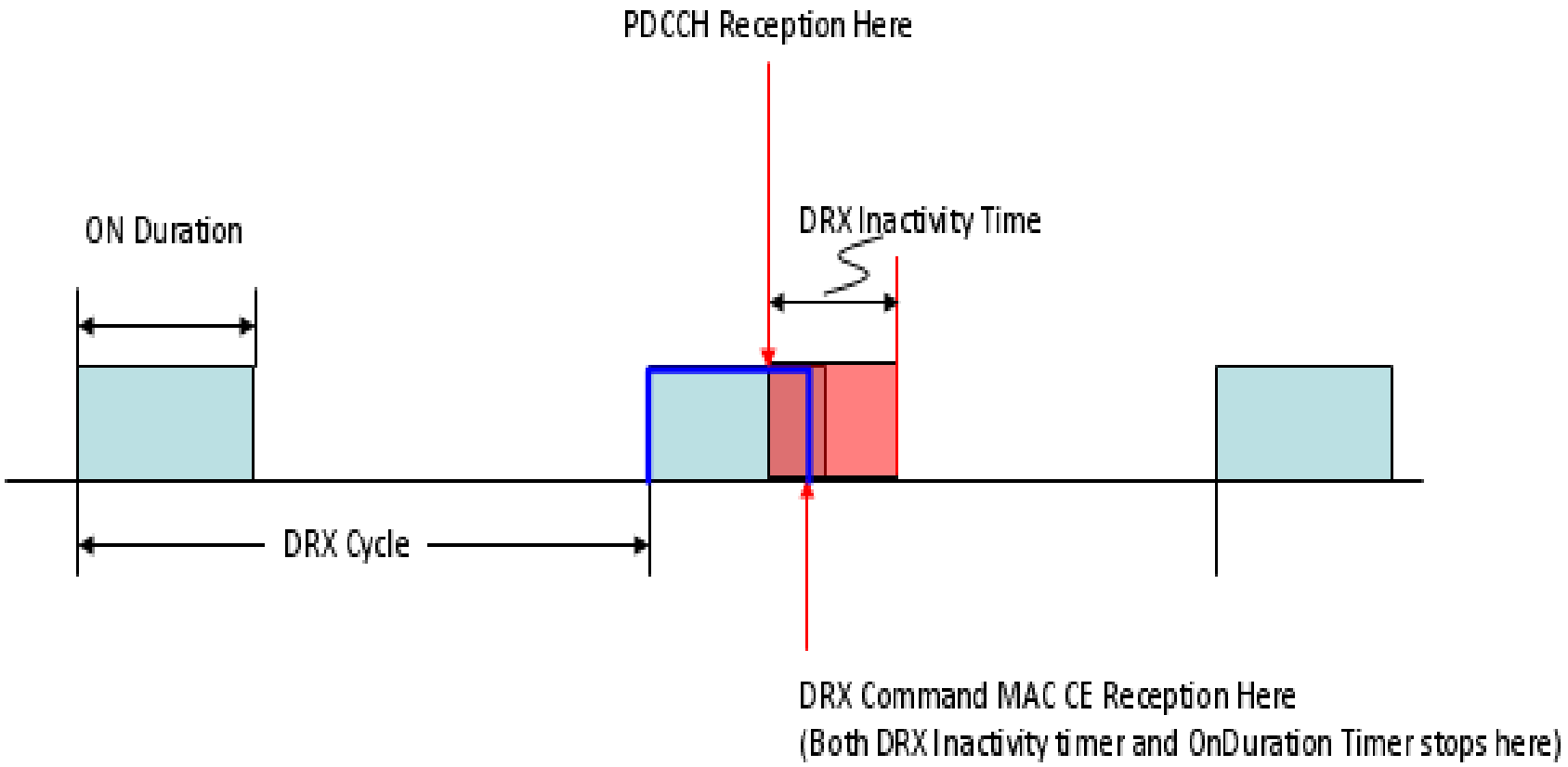
- **DRX Cycle:** The duration of one 'ON time' + one 'OFF time‘
- **shortDRX-Cycle:** DRX cycle which can be implemented within the 'OFF' period of a long DRX Cycle
  - Typically a few short cycles may be set after “on” time of a long DRX cycle
  - Just so that we go to the long “off” period only after “testing the waters” with no activity in the short DRX cycles
- **drxShortCycleTimer:** The consecutive number of subframes the UE shall follow the short DRX cycle after the DRX Inactivity Timer has expired

DRX Long and Short Cycles



DRX Short Cycles are Optional, and need to be configured; NORMAL DRX is the LONG DRX

Forcing UE to the “Off” State by DRX Command MAC Control Element



Active Time

- **Active-time**: Total duration that the UE is awake. This includes the
  - "On-duration" of the DRX cycle
  - The time UE is performing continuous reception while the inactivity timer has not expired
  - The time UE is performing continuous reception while waiting for a DL retransmission after one HARQ RTT
- Minimum active time is of length equal to on-duration
- Maximum is undefined (infinite)

Summary

- UL and DL Scheduling in LTE
- Semi-persistent Scheduling
- DRX